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Engineering and Design  
TREATABILITY STUDIES FOR  
SOLIDIFICATION/STABILIZATION OF  
CONTAMINATED MATERIAL

1. Purpose. This letter furnishes information and guidance on scoping a treatability study for solidification/stabilization (S/S) of contaminated material.

2. Applicability. This letter applies to all HQUSACE/OCE elements and USACE Commands having Hazardous, Toxic, and Radioactive Waste (HTRW) investigation and design responsibility.

3. References. References are listed in Appendix A.

4. Background. Solidification/stabilization is applicable for the treatment of contaminated liquids, soils, and sludges. This ETL will focus on S/S treatability studies for soils and sludges. S/S refers to treatment processes that are designed to accomplish one or more of the following: 1) improve the handling and physical characteristics of the waste; 2) decrease the surface area of the waste mass across which loss of contaminants can occur; and 3) reduce the solubility of hazardous constituents in the waste. The final product of an S/S process may vary from a granular, soil-like material to a cohesive solid depending on the amount of reagents added and the type of waste being treated. S/S can be performed as an in-situ process or the contaminated material can be excavated and treated above ground in some type of mixing unit.

a. Definitions. Solidification and stabilization refer to different processes which occur during treatment. The U.S. EPA has defined the terms as follows:

(1) Solidification. Solidification refers to techniques that encapsulate the waste in a monolithic solid of high structural integrity. The encapsulation may be of fine waste particles (microencapsulation) or of a large block or container of waste (macroencapsulation). Solidification does not necessarily involve a chemical interaction between the waste and the solidifying reagents, but may mechanically bind the waste into a monolith. Contaminant migration is restricted by decreasing the surface area exposed to leaching and/or by isolating the waste within an impervious capsule.

(2) Stabilization. Stabilization refers to those techniques which reduce the hazard potential of a waste by converting the contaminants into their least soluble, mobile or toxic form. The physical nature and handling characteristics of the waste are not necessarily changed by stabilization.

b. Application of Technology. Solidification/stabilization is a proven technology for the treatment of liquids, soils, and sludges contaminated with heavy metals. S/S of organic waste is difficult and care needs to be taken to carefully evaluate the effectiveness of such processes. Organics rarely react with treatment reagents, often volatilize during the S/S process, and often interfere with the reagent setting process. When significant levels of organic contamination are present, they should be removed by thermal treatment or biological processes prior to performing S/S. Selection of S/S as a remediation technology is also supported by recent developments in the environmental regulations. The following paragraphs address the Resource Conservation and Recovery Act and the Comprehensive Environmental Response, Compensation, and Liability Act as they pertain to the S/S of hazardous waste.

(1) Resource Conservation and Recovery Act (RCRA). RCRA was signed into law in 1976. The goal of RCRA is to promote protection of health and the environment from the careless disposal of waste products. In 1984, the Hazardous and Solid Waste Amendments (HSWA) to RCRA were signed into law. These amendments significantly expanded both the scope and requirements of RCRA. A key portion of the HSWA regulations is the establishment of treatment standards for every waste or group of similar wastes. Treatment standards are based on the performance of the best demonstrated available technology (BDAT) to treat the waste. Treatment standards can be established either as a specific treatment technology or as a concentration level based on a BDAT technology. The BDAT performance standard is based on S/S for several types of waste. It is important to understand the application of RCRA waste codes as they apply to wastes treated by S/S. There are two groups to consider, "Listed Wastes" and "Characteristic Wastes". Listed Wastes are wastes with codes beginning with F, K, P, or U. Once treated, these wastes retain their original waste code and must be managed as hazardous wastes unless formally delisted. Characteristic wastes are those hazardous wastes which are not specifically listed by the EPA and are not assigned a hazardous waste number, but which are found to be hazardous by one of the following characteristics: corrosivity, reactivity, ignitability, or toxicity. Characteristic wastes, once treated, are no longer

hazardous wastes unless they still exhibit a hazardous characteristic.

(2) The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA established a procedure for responding to releases of hazardous substances which ultimately involves site remediation actions potentially utilizing the S/S technology. CERCLA requires contaminated sites to be investigated, prioritized, and remediated. Requirements of other regulations such as RCRA, Clean Air Act, and Clean Water Act are integrated into the CERCLA process when evaluating alternative remedial actions by identification of what are referred to as Applicable or Relevant and Appropriate Regulations (ARARS). The Superfund Amendments and Reauthorization Act (SARA) was enacted in 1986. SARA reauthorized and further defined the CERCLA regulations. SARA strongly recommends remedial actions involving on-site treatment methods which reduce the toxicity, mobility or volume of hazardous substances. S/S is an applicable treatment technology based on these criteria since it reduces the mobility of contaminants.

c. Reagents. Reagents are the materials which are mixed with contaminated soils, sludges, and liquids to reduce the mobility of the contaminants by chemical and physical reactions. There are two basic types of S/S reagents, organic and inorganic. Organic reagents have rarely been used for the cleanup of hazardous waste sites. Therefore, this ETL will focus on the use of inorganic reagents. The normal processing steps when using inorganic reagents are to 1) chemically react with all the water present, 2) chemically react with the contaminants to render them insoluble, and then 3) encapsulate the products.

(1) Inorganic Reagents. Inorganic reagents most often used for S/S include portland cement, fly ash, lime, phosphates, and kiln dust from lime and cement production. All of these reagents have basically the same general types of active ingredients as far as S/S reactions are concerned. These active ingredients include  $\text{SiO}_2$ ,  $\text{CaO}$ ,  $\text{MgO}$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$ .

(2) Organophilic Clay. Organophilic clay has been proposed for use to adsorb organic contaminants so that they can be trapped in a solidified matrix. Lab tests have indicated that some organophilic clays chemically bond to organics. However, the strength of this bond is of concern. In most cases, the mechanism by which the organics are trapped is merely physical adsorption. Organophilic clays show some promise in combination with other reagents for the treatment of organics.

(3) Proprietary Processes. There are many proprietary processes available which are generally a combination of the above reagents. These proprietary processes may include additives to fix specific constituents, or anti-inhibiting agents to solidify wastes that are difficult to treat. A summary of proprietary processes and their applicability is provided in the text entitled "Chemical Fixation and Solidification of Hazardous Wastes" by Jess Conner.

(4) Mix Ratios. The optimum reagent to waste mix ratio is typically around .25 for contaminated soil. However, this ratio can vary anywhere from .1 to 2.0 depending on the contaminants present and the initial moisture content of the waste.

d. Treatment Technologies. S/S treatment can be performed either in-situ or ex-situ. In-situ treatment of soil is generally performed by injecting reagents into the ground and then mixing the reagents and contaminated soil with an auger. An ex-situ S/S system generally consists of a pug mill mixer, chemical storage and feed devices, pumps, conveyors, and metering and measuring equipment. Pumps or mechanical conveyors are used to transport the waste into a surge tank or feed hopper which in turn feeds the waste into the mixer where it is mixed with S/S reagents and water. Depending on the process used, one or more dry or liquid reagents may be added to the waste in the mixer. Typical mixing times are reported to range from 1 to 30 minutes. Stabilization reagents are often added prior to solidification reagents to allow the stabilizing reagents time to react with the contaminants. If the solidifying reagents are added too soon, they could inhibit the stabilization reactions. After mixing, the treated material is cured and then tested to verify it meets all physical and chemical parameters specified.

(1) Post-treatment testing requirements vary from project to project depending on the regulatory agencies involved. Post-treatment testing consists of both chemical and physical tests. Required chemical testing often consists of performing the Toxicity Characteristics Leaching Procedure (TCLP) and chemically analyzing the extract. Physical parameters tested will vary from project to project and may include unconfined compressive strength, permeability, and durability.

(2) Frequency of post-treatment testing is also subject to approval by regulatory agencies and varies from project to project. The most common frequency for testing is one set of tests per 400 to 800 cubic meters (500 to 1,000 cubic yards) of treated material. However, testing frequencies of greater than once every 75 cubic meters (100 cubic yards) have been used on

some Corps projects. During the remediation work, post-treatment testing creates logistics problems because of the need to allow material time to cure and the time required to perform the quality control testing. If the treated material is to be deposited in an off-site landfill, temporary lined and covered stockpiles are generally used to hold the material until testing confirms it meets all post-treatment criteria. At sites where the material will be deposited in an on-site landfill, it is generally placed directly into the landfill with requirements laid out in the specifications preventing the material from being covered by subsequent lifts until post-treatment testing is successfully completed.

e. Treatability Study Goals. Prior to performing an S/S treatability study, the objectives of the study should be clearly defined and the applicable regulatory requirements should be determined. A treatability study performed by the government can be performed during the remedial investigation, feasibility study, or design phase. Generally, the objective of a treatability study performed by the Government is to establish the feasibility of using a treatment process to protect the environment, public health, and welfare. Objectives of an S/S treatability study may also include one or more of the following:

- Determine the most economical mix design;
- Identify handling problems such as oversize material;
- Identify if volatile emissions are a concern;
- Assess physical and chemical uniformity of the waste;
- Determine volume increase associated with the S/S process.

To the greatest extent possible, a treatability study should be conducted in such a manner that it is representative of the full-scale remediation process. The results of a treatability study performed by the Government may be included in contract documents. However, these results should be provided for information only. The final mix design selected for use in the field should generally be the Contractor's responsibility. The method of disposal of the treated material often plays a critical role in structuring a treatability study since an off-site disposal facility may have more stringent requirements for the treated material than the regulatory requirements.

f. Treatability Study Samples. Sampling, handling, and waste characterization must be carefully considered so that a treatability study is run on material which is representative of site conditions. Evaluation of previous site characterization data should be carefully performed to determine locations for the collection of representative samples. Consideration should also

be given to how the contaminated material will be excavated and mixed during full scale treatment so that samples are representative of these conditions. Treatability studies performed by the Government are sometimes performed on the most highly contaminated material present. This will provide assurance that all the contaminated material at the site can be treated by the S/S process. However, this can also result in over-design and unrealistically high cost estimates. A better approach would be to test the most highly contaminated material present and material representative of average site conditions. The material representative of average site conditions would allow the treatment costs to be more accurately estimated during the design phase. Soil samples can be collected using backhoes, hollow stem augers, or they can be surface samples collected using hand tools. Sludge and liquid samples are typically collected using hand tools. Requirements for preparing a scope of work for collecting samples for investigations and studies are described in EM 200-1-3. The amount of contaminated material needed to perform an S/S treatability study will vary depending on the complexity of the study. A minimum of 40 liters (10 gallons) of material should be collected. However, most treatability studies require more material than this and an estimate of the amount of material needed should be made by determining the number and type of tests to be performed during the study.

(1) Sample Locations. In most instances, previous site characterization will have been performed prior to collection of samples for the treatability study. Therefore, judgmental sampling is the most common method of determining sample collection points. The judgmental sampling approach uses technical expertise to determine the most appropriate sampling location based on operational history, visual survey, and previous sampling. No matter how well a site has been characterized, heterogeneity may make collection of a representative sample difficult. To help alleviate this problem, field screening techniques can be used to quickly ensure the contaminants present in the samples are representative of site conditions. Field screening techniques include the following: soil gas, organic screening, flame ionizing detector (FID), photo ionization detector (PID), metals screening (geophysical, x-ray fluorescence), and PCB/PCP test kits. Refer to EPA/540/2-88/005 "Field Screening Methods Catalog, User's Guide" for a comprehensive discussion of field screening methods.

(2) Sample Homogenization. Prior to initial characterization of the samples at the laboratory, homogenization and removal of

oversize material by sieving are performed to create uniform samples for the treatability study.

(a) Particle size reduction is performed so that samples can be easily molded for testing. However, consideration should be given to how this will affect the properties of the sample relative to the waste that will be treated during full scale remediation. For example, if a material is going to pass a 2 inch field screen during full scale remediation, then it would be inappropriate to grind the sample in a mortar and pestle prior to testing during the treatability study.

(b) Samples are typically homogenized by a mechanical mixer in the laboratory. In some instances, samples have been homogenized in the field so that extra material can be stored on-site. This material has then been provided to potential bidders so that they could perform treatability studies using their own S/S reagents and mix ratios.

(3) Initial Sample Characterization. Initial sample characterization consists of performing both physical and chemical tests. Physical characterization tests typically performed include moisture content, grain size distribution, Atterberg limits, compaction, and possibly other tests depending on the project. Chemical testing typically performed includes total chemical analysis and leaching tests for the contaminants of concern. Refer to Paragraph 4.i. of this letter for additional information on typical characterization testing.

(4) Replicate Testing. Replicate testing is performed during various stages of a treatability study to determine the reproducibility of the chemical and physical test results. The amount of replicate testing depends on the type and phase of the project and on the amount of sample available. Replicate testing is typically performed during initial characterization to verify the uniformity of the samples being tested. Two or three sets of replicate tests are generally performed. Replicate testing can be performed by dividing the homogenized sample into two or three subsamples and performing identical sets of tests on each subsample.

g. Treatability Study Procedures. Following initial characterization, several reagents are selected and numerous mix ratios of waste, reagents, and water are prepared and tested to determine the optimum mix ratio. Mix ratio (MR) is defined as follows:

$$MR = \frac{\text{Weight of Reagent}}{\text{Weight of Waste}}$$

Mixing can be performed using mechanical devices with intermeshing ribbon or blade beaters. Various chemical and physical tests are used to judge the effectiveness of the mix ratios. A typical set of tests might include the following: an extraction procedure such as the TCLP to determine the amount of contaminants leaching from the treated material; unconfined compressive strength to provide an indication of physical stability; and additional physical properties established on a site-specific basis. Paragraph 4.i. describes some of the more common physical tests used during a treatability study. Additional chemical characterization testing may also be required for some treatability studies.

(1) Initial Testing of Mix Ratios. A treatability study is often performed in stages. Simple tests are performed in the initial stages to eliminate mix ratios which are obviously not going to be successful. Since physical characteristics are the easiest to test for, they will normally be addressed first. The initial test matrix will usually be a series of different reagent/waste/water combinations. A typical set of mix ratios might be created by using four reagents or reagent mixtures, each at two or more reagent to waste mix ratios and two or more water to waste ratios. The first parameter measured is strength development. Strength is determined using a cone penetrometer or an unconfined compressive strength test. Strength tests are usually performed after one to three days of curing. The required level of strength of the treated material is determined on a site specific basis. However, the treated material is usually required to have an unconfined compressive strength of at least 50 psi to ensure adequate bonding. The rationale for selecting this value is an attempt to require a bonding level in excess of that achieved by sorbents. A minimum compressive strength limit of 50 psi should also ensure the treated material will provide sufficient strength to support a landfill cover placed over the top of the material. In addition to strength test results, observations about the following attributes of the treated samples are often recorded:

- Is the sample spongy, powdery, granular, etc.?
- Is the surface softer than the underlying material?
- Is there excess water on the sample surface?
- Does the sample exude fluid when subjected to finger pressure?
- Is the fluid reabsorbed when the pressure is released?
- Has the color or odor changed?



- Has the sample expanded, shrunk, evolved gas, etc.?
- Did the temperature of the sample increase?
- Was the reaction between the waste and reagents violent?

If one or more of the initial test samples has satisfactory physical properties, that sample is then subjected to a leaching test. Replicate testing is often not performed during this stage of the treatability study. Using the information gained from the above tests, either a general S/S formulation is selected or the initial formulation step is reiterated using different reagents and/or mix ratios. When acceptable results have been obtained, the next step is optimization.

(2) Mix Design Optimization. During the optimization phase of the study, several of the most promising reagents and mix ratios are selected and a more thorough set of tests is performed on these mix ratios. The cure time for this phase of testing will usually be longer than during the initial mixing phase. Cure times are typically 3 to 28 days. Usually chemical leaching and several physical tests are performed on the test samples during this phase. Replicate testing should also be performed to provide assurance of the accuracy of the results. The subsamples used during the initial characterization stage can be used during this stage to create replicate samples.

h. Test Samples. Treatability study test samples must be prepared uniformly during each phase of testing in order to allow valid comparisons between the various mix ratios being tested. The following paragraphs describe typical sample preparation procedures.

(1) Sample Preparation. Many of the test methods used to evaluate the effectiveness of the S/S process during a treatability study do not specify sample molding requirements. To determine the density at which samples will be tested, a compaction test is often performed to determine maximum density and optimum moisture content. Based on the compaction data, samples are tested at some percentage of maximum density (typically 90 percent). Treated material is weighed out and compacted into molds which will produce samples with the correct length to diameter ratio for the tests which will be performed. In some instances pieces of the samples tested for unconfined compressive strength have been collected and tested for leachability.

(2) Curing Procedure. Samples are normally cured at 95-100 percent relative humidity at 20 to 25 degrees C in a temperature-humidity controlled chamber.

i. Physical Test Procedures. The following is a summary of the more common physical test procedures used when performing treatability studies.

(1) Strength. Strength testing is often used during a treatability study to indicate how well a material will endure stresses created by overburden and earth moving equipment. Strength test data is also frequently used to provide a baseline for comparison between unstabilized and stabilized waste. Unconfined compressive strength is the most commonly used strength parameter for S/S treatability studies. However, unconfined compressive strength is meaningful only for cohesive material. The following are the most commonly used test procedures for determining strength:

(a) Unconfined Compressive Strength (ASTM D 2166-91):  
Determines the behavior of the material under mechanical stress (soil-like materials).

(b) Unconfined Compressive Strength (ASTM D 1633-90):  
Determines the behavior of the material under mechanical stress (concrete-like materials).

(c) Unconfined Compressive Strength (ASTM C 109-91):  
Determines the behavior of 2 inch cube samples under mechanical stress (concrete-like materials).

(d) Pocket Penetrometer. The pocket penetrometer is a hand-held device that provides a crude estimate of the unconfined compressive strength of treated material. The test is performed by pushing a metal rod against the surface of the treated material and measuring resistance. A minimum sample size of 100 grams is required to provide enough material to minimize wall and bottom effects of the sample container. The test is sometimes used in the initial stages of a treatability study instead of unconfined compressive strength because of the speed at which it can be performed.

(e) Cone Penetrometer. The cone penetrometer is a more accurate test than the pocket penetrometer. The test procedure is described in FM 5-430-00-1. This test can be used to determine set time for treated material and can also be correlated to compressive strength. The test is sometimes used in the initial stages of a treatability study instead of unconfined compressive strength because of the speed at which it can be performed.

(2) Permeability. A maximum allowable permeability is sometimes specified for treated material by regulators. However, permeability testing should be used with caution since higher permeability is not necessarily related to leachability and the placement of low permeability waste within a landfill may result in ponded water within the landfill. The permeability of treated material is generally measured with a flexible wall permeameter using the test procedure described in ASTM D 5084-90. If permeability testing is to be performed as part of a treatability study, consideration needs to be given to the appropriate confining pressure, gradient, and permeating fluid which will be representative of field conditions.

(3) Durability. Durability tests are sometimes performed on treated samples during a treatability study. These tests are often used by comparing results with other test specimens (i.e., how many cycles can one mixture withstand versus a different mixture). The test procedures specified for durability testing of waste are entitled: Test Method for Determining the Resistance of Solid Wastes to Freezing and Thawing (ASTM D 4842-90) and Test Method for Wetting and Drying Test of Solid Wastes (ASTM D 4843-88).

(4) Moisture-Density (Compaction Tests). Compaction tests are run on treated and untreated material to determine compaction requirements for treatability study test specimens. Treated material is often compacted to around 90 percent of maximum density during a treatability study. It should be noted that optimum water content for compaction is often not the optimum water content required for hydration reactions. The two most commonly used compaction test methods are the standard (ASTM D 698-91) and modified (ASTM D 1557-91) compaction tests.

(5) Index Properties. Various index properties may be valuable in characterizing both untreated and treated material. The following is a partial list of these tests. Additional information on these test methods can be found in EPA/625/6-89/022.

(a) Moisture Content (ASTM D 2216-90): Generally used as a classification tool to determine the amount of free water present in a material. This test is often used to determine if pretreatment to remove free liquids is necessary. Moisture content can also be used to determine how well a sample has been homogenized prior to initial characterization testing.

(b) Apparent Specific Gravity and Bulk Density (ASTM D 5057-90): Bulk density is used to relate weight to volume for

material handling calculations. Calculated increases in the volume of material due to treatment help to determine the volume of landfill space required.

(c) Suspended Solids (Standard Methods 2540 D): Used to determine the amount of solids that do not settle from a column of liquid. Suspended solids content is an important parameter for determining material handling requirements such as whether or not the waste is pumpable. Suspended solids content can also be used to estimate the decrease in volume that can be achieved by dewatering.

(d) Particle Size Analysis (ASTM D 422-90): Generally used as a classification tool and as an indicator of difficulties that could be encountered in processing. Very fine or very coarse particles can increase the difficulty of performing S/S. Some contaminants tend to bind preferentially to small soil particles. Very large particles may require particle size reduction prior to treatment or removal and separate disposal.

(e) Atterberg Limits (ASTM D 4318-84): Used as a classification tool for the fine grained fraction of untreated material. Atterberg limits are used to estimate properties such as compressibility, strength, and swelling.

(f) Paint Filter Test (USEPA SW-846, Method 9095): The placement of bulk liquid hazardous waste or hazardous waste containing free liquid in any landfill is prohibited. The Paint Filter Test may be performed before or after treatment of a waste to determine if it contains free liquid.

(g) Bleed Water of Concrete (ASTM C 232-92): This test is used to measure the amount of water that will bleed from a freshly mixed sample of treated waste.

j. Chemical Test Requirements. ER 1110-1-263 prescribes Chemical Data Quality Management (CDQM) responsibilities and procedures for all chemical contamination investigative and remedial activities to assure that the analytical data obtained is of sufficient quality. The methods used for analyses of hazardous waste and leachate are contained and described in SW-846. EPA/625/6-89/022 provides additional information on chemical test procedures typically used for an S/S treatability study.

(1) Project Chemist. The project chemist must collaborate with the design engineer in formulating the appropriate analytical requirements to meet the data quality objectives of

the treatability study. The following factors should be considered when selecting methods to analyze and appropriate quality control measures for implementation of the treatability study:

- stage of project;
- contaminants of interest;
- sample media;
- anticipated number of samples;
- likely range of contaminant concentration;
- analytical turnaround time;
- identification or quantification or both required;
- required quantitation limit;
- cost.

(2) Data Quality Objectives (DQOs). Data Quality Objectives are defined as an integrated set of thought processes which define data quality requirements based on the intended use of the data. All project specific data quality objectives must be clearly defined within the appropriate project plan. During a treatability study, the data is used to verify that regulatory levels can be attained or disposal criteria can be met. Data errors which occur during a treatability study could have a considerable impact during later phases of the project. For this reason, DQOs established are normally quantitative and stringent.

(3) Analytical Protocol. DQOs are established quantitatively with appropriate ranges. The analytical protocol used to support these DQOs should require positive identification and quantitation of contaminants of concern, therefore, standardized test methods should be used.

(4) PARCC Parameters. Precision, accuracy, representativeness, completeness, and comparability (PARCC) parameters must be established for the chemical tests performed during a treatability study.

(a) Precision is the measure of the level of random error associated with a given set of measurements, calculated using standard deviation or relative percent difference in replicate analysis, and is determined by the objectives of the project. Precision is commonly assessed by taking a sufficient number of samples, including replicates.

(b) Accuracy is the estimate of the relative agreement of the measured value with the true or expected value. Accuracy is controlled by prescribing appropriate sampling procedures, sample handling (including preservation) and analytical procedures.

Strict adherence to standard operating procedures during sampling and analysis, and avoiding field cross-contamination by implementation of thorough decontamination procedures will ensure a high degree of accuracy.

(c) Representativeness is the degree to which data accurately and precisely portrays the environmental conditions being studied.

(d) Comparability is the qualitative estimate of the relative confidence with which the data obtained from one set of measurements may be compared to data from another set of measurements. The degree of comparability is directly related to the precision, accuracy, and representativeness of the data in each set. Factors that are likely to contribute to systematic and random error of the data should be evaluated and appropriate methods that allow collection of the type, quality, and quantity of data needed for the treatability study should be selected.

(e) Completeness is the estimate of the number of valid measurements made as compared to the total number of measurements performed. The level of completeness required for a given set of data is determined by the number of valid measurements that must be obtained to satisfy the data use. To emphasize, comparability and representativeness are qualitative objectives of the data; while completeness goals are defined for individual sampling and analytical protocols or may be combined to assess the project as a whole. Precision and accuracy parameters, on the other hand, represent quantitative limits below which data is unacceptable, and corrective action must be taken.

(5) Application of PARCC Parameters. Precision and accuracy goals may be established at levels specified within the methods or more stringent as required by project DQOs. If no goals are presented within the methods, project specific ranges must be established for precision and accuracy in order to generate data of consistent quality throughout the study.

(6) QA/QC Procedures. Quality assurance/quality control procedures are a program of field and laboratory operations employed to assess the validity of the sampling and analytical work performed. Sampling QA/QC procedures normally require the acquisition of replicate samples (field duplicates, splits, etc.) and associated blanks (rinsates, trip blanks, etc.). Laboratory QA/QC procedures encompass the required analysis of method blanks, duplicate samples, surrogate compounds, spike samples, etc. These operations allow calculation of both field and laboratory precision and accuracy achieved in conjunction with

the data. These data quality indicators are then compared to those parameters established at the initiation of the project to assess contract compliance.

k. Leaching Procedures. The primary objective of S/S is to immobilize contaminants in waste. Leachability testing is used to predict how well contaminants have been immobilized. No single leaching test procedure can duplicate all possible field conditions. Ideally, the treated waste would be leach-tested with the actual surface water, ground water or rain water present at the site. In practice, this is rarely possible, both because of lack of definitive knowledge about site conditions and because of regulatory philosophy. Therefore, standard leachability tests have been developed by the EPA and several states. The major test variables are normally specified for a given test procedure, but latitude in the specification and controllability of the variables can cause significant problems with reproducibility. Most of the tests presently used for regulatory purposes are batch procedures in which the waste is contacted with a leachate for a specific period of time, agitating the mixture to achieve continuous mixing. Chemical equilibrium is often obtained, especially when the solidified waste is crushed before extraction. After extraction and separation of the leachate fluid from the solid waste, the leachate is analyzed for specific constituents. Most of these tests use a leachate to waste ratio of 20:1 so that the maximum concentration of constituent which can be attained in the leachate is 5% of that in the original solid waste. The leachate used in most cases is a dilute acid. The total amount of acid added varies with the test and/or with the alkalinity of the waste. The pH of the leachate at the end of the test is usually controlled by the alkalinity of the waste when the leachate is deionized water or dilute acid. Final pH is one of the controlling factors in metal leaching.

l. TCLP. The TCLP is the regulatory leaching procedure currently used in the United States. The TCLP involves passing the solid portion of a sample through a 9.5 mm sieve. The sample is then placed in a rotary agitation device along with an acetic acid solution at a ratio of 1 part waste to 20 parts acetic acid. The sample and acid solution are then mixed for 18 hours in the rotary agitation device at a rate of 30 revolutions per minute. Once the mixing has been completed, the acetic acid solution is analyzed to determine how much of the contaminants have leached out of the sample. If the amount of contaminants that have leached out exceeds regulatory criteria, then the waste is classified as hazardous. The complete procedure for the TCLP is described in SW-846, Method 1311. Some precautions about

interpreting the results of the TCLP are provided in the following paragraphs.

(1) The TCLP is designed to simulate the leaching potential of a waste within an unmanaged landfill designed for municipal refuse. Such landfills are known to generate organic acids during decomposition of organic matter in the refuse. The purpose of acetic acid in the leachant is to simulate those acids. However, the test does not simulate the conditions of most present-day hazardous waste landfills because these landfills often contain very little biodegradable organic matter.

(2) If the TCLP is used for cement-based waste forms, it may not yield maximum concentrations of contaminants. This is the result of the acetic acid solution not being able to sufficiently reduce the elevated pH caused by the crushed cement. Thus, an unground sample could exhibit more leaching than a ground sample in the TCLP test.

(3) Some metals are amphoteric which means they are more soluble at both low and high pH values. Solidified waste is generally caustic and, when mixed with the acetic acid solution, could lower the pH to the point where the metals exhibit minimum solubility. If this occurs, the quantity of metals leached would be lower than those leached under natural conditions.

(4) The goal of S/S is to protect the environment, not simply to pass the TCLP test. Other extraction tests can be used to assess maximum leachate concentrations and to better simulate actual field conditions. A partial summary of other leaching test procedures is presented in EPA/625/6-89/022. No leaching test can simulate all real world conditions that the treated waste may be exposed to and no information regarding the long-term performance of S/S processes is available. Therefore, physical tests such as durability, strength, and permeability can be used to help evaluate the long-term effectiveness of the S/S process. Surface area effects can also be studied by crushing the leach test samples to varying degrees.

m. Sampling and Analysis Plan. A Sampling and Analysis Plan (SAP) should be incorporated into the treatability study work plan if the contractor will also be responsible for sample collection. A SAP is prepared to ensure that test data, acquired during both sample collection and performance of the treatability study, is of sufficient quality to meet the intended uses. Data quality depends not only on how carefully a test method is carried out, but also on the sample point selection, sampling procedures, sample integrity and test methods selected. Data



quality objectives should be defined in the scope of work to help guide the Contractor in determining required sampling procedures and test methods. Requirements for the contents of a SAP are described in EM 200-1-3. EP 200-1-2 provides guidance on manifesting RCRA hazardous waste.

n. Data Interpretation. Standard procedures are not available for interpretation of the data from an S/S treatability study. The results of the chemical and physical testing must be compared against the regulatory criteria for the treated material.

(1) Dilution Effect. The results of leaching tests for treated samples should be compared with the results for untreated samples. The binder and water added during S/S will dilute the waste. Therefore, the data must be normalized to the dry raw waste content. The data can then be presented as a percent treatment effectiveness to determine the benefits of S/S and to compare the various mix ratios. The following equation can be used to take into account the affect of dilution by the reagents:

$$\text{Percent Reduction} = 100(1 - (1 + \text{AR}) \frac{(\text{Treated TCLP Conc.})}{(\text{Raw TCLP Conc.})})$$

$$\text{AR} = \text{Additive Ratio} = \frac{\text{Weight of Additive}}{\text{Weight of Waste}}$$

(2) Bulking Factor. The bulking factor is the amount of volume increase that will occur as a result of the addition of treatment reagents. Frequently a maximum allowable bulking factor will be one of the criteria established for a treatability study. The following equation can be used to determine the bulking factor (B):

$$B = (1 + R) * \frac{D \text{ insitu}}{D \text{ treated}} * \frac{1 + MC \text{ treated}}{1 + MC \text{ insitu}} - 1$$

R = Dry weight ratio of solidifying agent to waste

D insitu = Bulk unit weight of insitu waste

D treated = Bulk unit weight of compacted treated material

MC insitu = Moisture content of insitu waste

MC treated = Moisture content of treated material

(3) Optimum Reagents and Mix Ratios. Based on the treatability study results, the reagents and mix ratios which

most economically achieve the chemical and physical treatment criteria should be selected.

5. Discussion.

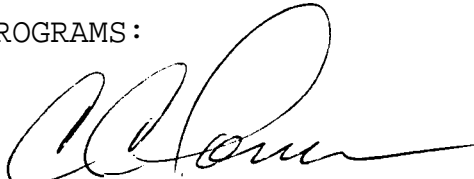
a. Appendix B provides an outline of topics which should be considered for inclusion in a Solidification/Stabilization Treatability Study Scope of Work (SOW). Not all topics in the outline are appropriate for each project. The designer should select the sections of the SOW which are applicable on a **site-specific** basis. Under some circumstances, additional scope topics should be developed to supplement those presented here. The outline is supplemented by text describing the typical requirements for each topic. Other documents are also referenced which describe standard requirements which should be incorporated into an S/S treatability study SOW.

b. Based on the treatability study SOW, the Contractor will prepare a work plan outlining all tasks to be performed during the treatability study. The work plan will be reviewed and approved by USACE prior to the Contractor initiating any work on the treatability study.

c. Input during the preparation of the technical portions of . . . . a SOW should be sought from the appropriate technical staff within USACE. Waterways Experiment Station has performed numerous S/S treatability studies and should be consulted when scoping a complex treatability study. The involvement of **in-house** technical expertise in scoping any phase of an HTRW project is essential to providing a cost-effective high quality service to the customer **and** to providing quality reviews of subsequent submittals.

FOR THE DIRECTOR OF MILITARY PROGRAMS:

2 Appendices  
**APP A** - References  
**APP B** - Scope of Work  
(SOW) Outline for a  
**Solidification/Stabili-**  
**zation Treatability Study**

  
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